

DETECTION OF ENGINE ROTATION SPEED IN SPARK IGNITION INTERNAL COMBUSTION ENGINE

FIELD OF THE INVENTION

[0001] This invention relates to detection of the engine rotation speed in a spark ignition internal combustion engine.

BACKGROUND OF THE INVENTION

[0002] JP2001-082302A published by the Japanese Patent Office in 2001 discloses ignition timing control of an internal combustion engine using a rotation speed of the engine as a parameter. A crank angle sensor detects the engine rotation speed. The crank angle sensor outputs a signal when the crankshaft of the engine reaches a defined reference rotation position for each cylinder.

[0003] A separate signal is outputted when the crank shaft rotates through a unit angle which is set for example to one degree. The former signal is termed a reference position signal or a *REF* signal and the latter is termed a unit crank angle signal or a *POS* signal.

[0004] The engine rotation speed is obtained by measuring the interval between the *REF* signal and the *POS* signal. Since the *POS* signal is updated more frequently than the *REF* signal, the rotation speed obtained from the *POS* signal has a higher tracking ability of the real rotation speed of the engine than that obtained from the *REF* signal.

SUMMARY OF THE INVENTION

[0005] When the control of the ignition timing, the fuel injection amount or the fuel injection timing of the engine is executed at short intervals such as ten milliseconds, the engine rotation speed is calculated on each cycle using the *POS* signal. In this case, when the detection timing of the *POS* signal overlaps with the spark plug ignition, there is the possibility that ignition noise will be mistakenly detected as a *POS* signal. As a result, a large error may be introduced into the calculation of the engine rotation speed.

[0006] It is therefore an object of this invention to eliminate the effect of ignition noise on detection of the engine rotation speed.

[0007] If the control of the ignition timing, the fuel injection amount or the fuel injection timing of the engine is executed on a fixed cycle, the control target value for the ignition timing, the fuel injection amount and the fuel injection timing are updated on a fixed cycle. The control target value is then set to a register. Actual ignition or fuel injection is performed at a specific crank angle which corresponds to the target ignition timing or the target fuel injection timing. As a result, there is a time lag between the time the *POS* signal is detected for the calculation of the engine rotation speed and the time at which ignition or fuel injection is actually performed. Thus when the rotation speed of the engine undergoes a large fluctuation, this time lag reduces the accuracy of the control routine. When the detection of the engine rotation speed and the control target value are updated using the crank angle, in other words, when the updating process is performed in synchronism with the *REF* signal, the period from the detection of the engine rotation speed to actual fuel injection or ignition becomes fixed. Thus it is possible to improve control accuracy. However in this case, the control interval varies depending on the engine rotation speed, so the calculation

load per unit time required for updating the control target value becomes excessively large at high engine rotation speeds.

[0008] It is a further object of this invention to shorten the time period from detecting the engine rotation speed to the control of the fuel injection or ignition without excessively increasing the calculation load.

[0009] In order to achieve the above objects, this invention provides an operation control device for an spark ignition internal combustion engine performing ignition in a fixed ignition crank angle range, comprising a unit crank angle sensor which output a unit crank angle signal corresponding to a unit crank angle of the engine; and a programmable controller programmed to calculate an engine rotation speed based on the unit crank angle signal while preventing the calculation of the engine rotation speed based on the unit crank angle signal detected in the ignition crank angle range from being performed, and control the engine according to the engine rotation speed.

[0010] This invention also provides an operation control method for an spark ignition internal combustion engine performing ignition in a fixed ignition crank angle range. The method comprises detecting a unit crank angle signal of the engine, calculating an engine rotation speed based on the unit crank angle signal while preventing the calculation of the engine rotation speed based on the unit crank angle signal detected in the ignition crank angle range from being performed, and controlling the engine according to the engine rotation speed.

[0011] The details as well as other features and advantages of this invention are set forth in the remainder of the specification and are shown in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a schematic diagram of an engine control device according to this invention.

[0013] FIG. 2 is a block diagram describing the function of a controller according to this invention.

[0014] FIG. 3 is a flowchart describing a routine for controlling fuel injection and spark ignition of the engine executed by the controller.

[0015] FIG. 4 is a diagram describing a *POS* signal detection timing according to this invention.

[0016] FIGs. 5A – 5G are timing charts showing the difference in the ignition timing control caused by the rotation speed based on a *POS* signal and the rotation speed based on a *REF* signal.

[0017] FIGs. 6A and 6B are diagrams showing the error caused by the detection timing of the *POS* signal on the engine rotation speed.

[0018] FIG. 7 is a flowchart showing a signal switching routine executed by the controller according to a second embodiment of this invention.

[0019] FIGs. 8A – 8F are timing charts showing the effect of control executed by the controller according to the second embodiment of this invention.

[0020] FIG. 9 is a diagram describing noise mixing in the *POS* signal.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Referring to FIG. 1 of the drawings, a four-stroke cycle six-cylinder V-shape engine 2 applying this invention comprises an intake pipe 3 and an exhaust pipe 23. The intake pipe 3 is connected via an intake port 7 provided with

an intake valve 20 to the combustion chamber 6 of each cylinder. The exhaust pipe 23 is connected to the combustion chamber 6 of each cylinder via an exhaust port 22 provided with an exhaust valve 21.

[0022] An electronic throttle 5 is provided in the intake pipe 3. A fuel injector 8 is provided in proximity to the intake valve 20 in the intake port 7. One fuel injector 8 is provided for each cylinder. Gasoline fuel is supplied at a fixed pressure to the fuel injector 8. When the fuel injector 8 is opened, an amount of gasoline fuel which corresponds to the lift period is injected towards the intake air entering from the intake port 7 to the combustion chamber 6.

[0023] The fuel injection timing and the fuel injection amount from the fuel injector 8 of each cylinder are controlled by a pulse signal output from the controller 1 to each fuel injector 8. The fuel injectors 8 initiate fuel injection simultaneously with the input of the pulse signal and injection is continuously performed during an interval equal to the pulse width of the pulse signal.

[0024] A gaseous mixture with a fixed air-fuel ratio is produced in the combustion chamber 6 of each cylinder as a result of the fuel injection from the fuel injector 8 and the intake air from the intake pipe 3. A spark plug 24 facing the combustion chamber 6 is sparked in response to a high-voltage current produced by an ignition coil 14 and ignites and burns the gaseous mixture in the combustion chamber 6. The ignition timing of the spark plug 24 is controlled by an ignition signal output from the controller 1 to the ignition coil 14.

[0025] The stroke pattern of the four-stroke cycle engine 2 comprises an intake stroke, a compression stroke, an expansion stroke and an exhaust stroke. These four stroke cycles vary with respect to the top dead center (TDC) and the bottom dead center (BDC) defined by the vertical motion of the piston in each

cylinder.

[0026] Ignition is performed in this type of engine 2 in a fixed advance range from a compression top dead center (CTDC) which is the end point of the compression stroke for each cylinder. In other words, ignition is performed during the compression stroke. The angular range expressed by a crank angle is termed an ignition crank angle range.

[0027] The controller 1 comprises a microcomputer provided with a central processing unit (CPU), a read-only memory (ROM), a random access memory (RAM) and an input/output interface (I/O interface). The controller 21 may comprise a plurality of microcomputers.

[0028] Signals representing detection data are input to the controller 1 for fuel injection control and ignition control. Signals are input from an air flow meter 4 detecting an intake air amount in the engine 2, a crank angle sensor 9, a cam position sensor 11, an ignition switch 13, a water temperature sensor 15 detecting a cooling water temperature of the engine 2 and an oxygen sensor 16 detecting an oxygen concentration in the exhaust gas from the engine 2.

[0029] The crank angle sensor 9 outputs a *REF* signal when a crankshaft 10 of the engine 2 arrives at a reference rotation position. Furthermore a *POS* signal is output when the crankshaft 10 rotates through a unit angle which is set for example at one degree. The reference rotation position corresponds to a rotation position 110 degrees before the top dead center (TDC) for each cylinder in a six-cylinder sixty degree V-shape engine.

[0030] The cam position sensor 11 outputs a *PHASE* signal in response to a specific rotation position of the cam 12 driving the exhaust gas valve 21. In a four-stroke cycle engine 2, ignition is performed in each cylinder once for every two

REF signals. The top dead center (TDC) comprises a compression top dead center (CTDC) and an exhaust top dead center (ETDC). The controller 1 discriminates these signals based on the combination of the *REF* signal and the *PHASE* signal.

[0031] The ignition switch 13 places the spark plug 24 by outputting an ignition signal *IGN* in a state where ignition can take place. The ignition switch 13 also outputs a start signal *StartSW* in order to start the operation of a starter motor cranking the engine 2.

[0032] Referring to FIG. 2, the controller 1 comprises a startup initiation discrimination section 101, a cylinder discrimination section 102, a rotation speed signal production section 103, an injection pulse width calculation section 104, an injection start timing calculation section 105, an injector drive signal output section 106, an ignition signal calculation section 107 and an ignition signal output section 108. Each of these sections is a virtual section representing the functions of the controller 1 and does not have physical existence.

[0033] The startup initiation discrimination section 101 detects startup of cranking of the engine 2 based on the start signal *StartSW* and the ignition signal *IGN* from the ignition switch 13. Engine startup is determined when the start signal is ON.

[0034] The cylinder discrimination section 102 uses the *POS* signal output by the crank angle sensor 9 and the *PHASE* signal output by the cam position sensor 11 in order to determine the respective stroke positions of each cylinder of the engine 2. In the description hereafter, this determination is termed cylinder discrimination.

[0035] The rotation speed signal production section 103 calculates an engine rotation speed *LNRPM* based on the output interval of the *REF* signal from the

crank angle sensor 9. The rotation speed signal production section 103 also calculates an engine rotation speed *FNRMP3* based on the output interval of the *POS* signal from the crank angle sensor 9. However the *POS* signal used in the calculation according to this invention is limited to *POS* signals detected outside the ignition crank angle range. This range is termed as a non-ignition crank angle range.

[0036] The injection pulse width calculation section 104 calculates the basic fuel injection pulse width by looking up a pre-stored map based on the engine rotation speed calculated by the rotation speed signal production section 103 and the intake air amount detected by the air flow meter 4.

[0037] The injection pulse width calculation section 104 determines a target fuel injection pulse width by adding a correction to the basic fuel injection pulse width so that the gaseous mixture in the combustion chamber 6 coincides with a fixed target air-fuel ratio. The fuel correction amount is calculated based on the oxygen concentration in the exhaust gas detected by the oxygen sensor 16 and the cooling water temperature detected by the water temperature sensor 15.

[0038] When starting the engine 2, the injection pulse width calculation section 104 determines the target fuel injection pulse width using a method described hereafter which differs from the method for normal operating states.

[0039] The injection initiation timing calculation section 105 calculates the target initial timing of the fuel injection based on the injection pulse width and the engine rotation speed.

[0040] The injector drive signal output section 106 outputs a pulse signal for the target fuel injection pulse width to the fuel injector 8 at the target start timing for fuel injection.

[0041] The ignition signal calculation section 107 determines a target ignition timing of the spark plug 24 based on the engine rotation speed and the water cooling temperature of the engine 2.

[0042] The ignition signal output section 108 sparks the spark plug 24 by controlling current supply to the ignition coil 14 at a target ignition timing based on the *POS* signal and the *REF* signal.

[0043] Next, referring to FIG. 3, a control routine for the fuel injection and ignition of the engine 2 executed by the controller 1 as structured above will be described hereafter. This routine is executed at intervals of ten milliseconds while the engine 2 is operating.

[0044] Firstly in a step S1, the controller 1 calculates the engine rotation speed *FNRPM3* based on the interval of the most recent *POS* signal detected outside the ignition crank angle range.

[0045] Referring to FIG. 4, the determination of the ignition crank angle range determined in the step S1 will be described below. In a six-cylinder V-shape engine, a *REF* signal is output at 110 degrees before top dead center (110 degree BTDC) for each cylinder. The ignition timing during engine startup is delayed at most until the compression top dead center (CTDC). After engine startup, the ignition timing is advanced in a fixed angular range in response to the increase in the rotation speed. The fixed advance angular range from CTDC is taken to be the ignition crank angle range in view of the possibility that ignition takes place depending on operating conditions.

[0046] In the step S1, the calculation of the engine rotation speed *FNRPM3* based on the *POS* signal detected in the ignition crank angle range set as described above is prohibited. This is achieved by calculating the engine rotation speed

FNRPM3 based on the interval of the most recent *POS* signal detected in the non-ignition crank angle range. As a result, a time lag necessarily results between the input of the *POS* signal forming the basis of the calculation and the time the engine rotation speed *FNRPM3* is actually calculated. The controller 1 sequentially stores the *POS* signals and the *REF* signals input from the crank angle sensor 9 in the memory. The controller 1 selects the most recent two *POS* signals in the non-ignition crank angle range from among the stored *POS* signals in the memory (RAM) and calculates the engine rotation speed *FNRPM3* on the basis of the interval of these signals.

[0047] In FIG. 4, the interval from the compression top dead center (CTDC) to the *REF* signal REF110 input immediately thereafter always resides in the non-ignition crank angle range. In the step S1, it is also preferred that the engine rotation speed *FNRPM3* is calculated from the interval of the most recent *POS* signal obtained in the range between CTDC and *REF* 110.

[0048] Detection of the *POS* signal without interference from ignition noise is achieved by limiting the detection interval of the *POS* signal to the non-ignition crank angle range. Thus it is possible to improve the calculation accuracy of the engine rotation speed. This routine allows the calculation of the engine rotation speed *FNRPM3* to be calculation only once every ten milliseconds rather than being dependent on the input frequency of the *REF* signal. Thus the calculation load is not increased even in high rotation engine performance regions in which the input frequency of the *REF* signal is high.

[0049] In a step S2, the controller 1 calculates the engine rotation speed *LNRPM* from the most recent input interval of the *REF* signal.

[0050] In a step S3, the controller 1 uses the engine rotation speed *FNRPM3*

and the intake air amount detected by the air flow meter 4 in order to calculate the basic fuel injection pulse width by looking up a map which is pre-stored in the memory (ROM). The injection pulse width is determined by adding a correction to the basic fuel injection pulse width so that the gaseous mixture in the combustion chamber 6 coincides with a fixed target air-fuel ratio. The correction is based on the oxygen concentration in exhaust gas detected by the oxygen sensor 16 and the cooling water temperature detected by the water temperature sensor 15.

[0051] Then in a step S4, the controller 1 determines the ignition timing of the spark plug 24 on the basis of the cooling water temperature of the engine 2 and the engine rotation speed *FNRPM3*.

[0052] Next in a step S5, the controller 1 calculates the start timing for fuel injection based on the engine rotation speed *FNRPM3* and the injection pulse width.

[0053] Finally in a step S6, the controller 1 sets the ignition timing, the start timing for fuel injection and the injection pulse width to a register. The output of the ignition signal to the ignition coil 14 and the output of the fuel injection pulse signal to the fuel injector 8 are both performed at the set timing.

[0054] Referring to FIGs. 5A – 5G, the difference on ignition timing control during engine startup which results from using the engine rotation speed *LNRPM* based on the *REF* signal and using the engine rotation speed *FNRPM3* based on the *POS* signal will be described.

[0055] The *REF* signal does not display a high correspondence to the actual engine rotation speed due to the low updating frequency in comparison to the *POS* signal. As a result, as shown in FIGs. 5C – 5D, when the engine rotation speed undergoes a large increase during engine startup for example, the engine rotation

speed *LNRPM* based on the *REF* signal is a smaller value than the real engine rotation speed.

[0056] The ignition timing which maximizes the engine output shaft torque is termed the minimum spark advance for best torque (MBT). MBT is delayed as the engine rotation speed decreases. As a result, when the ignition timing is set according to the engine rotation speed *LNRPM* obtained from the *REF* signal while the engine rotation speed is increasing, the ignition timing is delayed from the preferred ignition timing as shown by the broken line in FIG. 5F. Consequently it is not possible to obtain a sufficient shaft torque. Thus when calculating the ignition timing, it is preferred to use the engine rotation speed *FNRPM3* based on the *POS* signal which displays a high correspondence to the actual engine rotation speed.

[0057] This problem does not always arise after startup when the engine rotation speed does not undergo a large variation. Thus only while the startup signal is ON as shown by FIG. 5G, the ignition timing is set using the engine rotation speed *FNRPM3* based on the *POS* signal. After the start signal *StartSW* shifts to OFF, it is possible to set the ignition timing using the engine rotation speed *LNRPM* based on the *REF* signal.

[0058] Next referring to FIGs. 6A and 6B, FIG. 7 and FIGs. 8A-8F, a second embodiment of this embodiment will be described.

[0059] Firstly referring to FIGs. 6A and 6B, the relationship between the detection timing of the *POS* signal and the real engine rotation speed will be described. The engine rotation speed *FNRPM3* based on the *POS* signal approximates the real engine rotation speed more than the engine rotation speed *LNRPM* based on the *REF* signal. This is particularly the case during the high variation in the

engine rotation speed when starting the engine. During the high engine rotation variation in engine startup, as shown in FIG. 6B, it is sometimes the case that variation of up to 175 revolutions per minute (rpm) for example is experienced in the engine rotation speed during the ten milliseconds before the *REF* signal. Thus even when the engine rotation speed is calculated based on the *POS* signal, when there is a time lag between the time the *POS* signal is detected and the time fuel injection or ignition is actually performed, accurate control on ignition timing, fuel injection amount or the fuel injection timing is not possible. The fuel injection or ignition is performed at a fixed crank angle. Thus when control on fuel injection or ignition is performed at a fixed time cycle, the degree of time lag fluctuates in each control cycle.

[0060] The interval from the compression top dead center (CTDC) to input of the *REF* signal immediately thereafter always resides in the non-ignition crank angle range as described above. In this embodiment, during engine startup in which the engine rotation speed undergoes a considerable increase, control of the ignition and the fuel injection is executed synchronous with the *REF* signal input immediately after the compression top dead center (CTDC). However, after completion of engine startup, these control routines are executed at fixed time intervals.

[0061] In this embodiment, the controller 1 executes a signal switching routine as shown in FIG. 7 in order to switch the control cycle. This routine is performed every ten milliseconds.

[0062] Referring to FIG. 7, firstly in a step S11, the controller 1 determines whether or not the start signal *StartSW* is ON.

[0063] When the start signal *StartSW* is ON, in a step S12 the controller 1 determines that the routine in FIG. 3 is executed synchronously with the *REF*

signal.

[0064] When the start signal *StartSW* is not ON, in a step S13, the controller 1 determines that the routine in FIG. 3 is executed every ten milliseconds. After the process in the step S12 or S13, the controller 1 terminates the routine.

[0065] As shown in FIG. 8B and 8F, while the start signal *StartSW* is ON, the routine shown in FIG. 3 is executed synchronously with the *REF* signal. After the start signal *StartSW* is OFF, the routine in FIG. 3 is executed at an interval of ten milliseconds.

[0066] In a six-cylinder V-shape engine, six *REF* signals are output per revolution. Fuel injection and ignition are performed every three revolutions. Therefore executing the control routine for fuel injection and ignition in FIG. 3 at an interval of ten milliseconds is equal to executing the routine synchronous to the *REF* signal when the engine rotation speed is 2000 rpm. When the engine rotation speed is less than 2000 rpm, the control period for the execution of the routine synchronous to the *REF* signal exceeds an interval of ten milliseconds. As shown in FIG. 8C, when the rotation speed of the engine 2 is normally less than 2000 rpm during startup, execution of the routine synchronous with the *REF* signal actually decreases the calculation load.

[0067] On the other hand, when the routine in FIG. 3 is performed synchronous with the *REF* signal, the *POS* signal is detected immediately before the *REF* signal and the calculation operations in the steps S3 – S5 are performed immediately thereafter. Thus it is possible to perform accurate detection of the engine rotation speed.

[0068] In comparison to the first embodiment, this embodiment makes it possible to increase the control accuracy on fuel injection and ignition during

startup of the engine 2 and decrease the calculation load on the controller 1 during engine startup.

[0069] Referring to FIG. 9, a third embodiment of this invention will be described.

[0070] This embodiment relates to a detection method for the *POS* signal. In the first and second embodiments, the undesirable effect of engine ignition noise on detection of the *POS* signal is eliminated by calculating the engine rotation speed based only *POS* signals outside the ignition crank angle range.

[0071] In this embodiment, exhaust noise is completely eliminated for the detection of the *POS* signal by calculating the engine rotation speed based on the *POS* signal at least three times in succession and using the smallest of those values as the engine rotation speed *FNRPM3*.

[0072] Referring to the *POS* signals *p1*, *p2* and *p3* in FIG. 9, it is assumed that a noise component *pn* is interposed between *p1* and *p2*. The apparent *POS* signal interval in this case becomes *p1 - pn*, *pn - p2* and *p2 - p3*. If we assume that the controller 1 detects the output interval of the *POS* signal on three successive occasions and calculates the engine rotation speed on the basis of the largest value for those three output intervals, the pulse interval *p2 - p3* which is not affected by noise will form the basis of the resulting engine rotation speed. In the step S1 in FIG. 3, when this calculation method is applied to the calculation of the engine rotation speed *FNRPM3*, it is possible to obtain an accurate engine rotation speed *FNRPM3* free of the effects of noise.

[0073] The contents of Tokugan 2002-369849, with a filing date of December 20, 2002 in Japan, are hereby incorporated by reference.

[0074] Although the invention has been described above by reference to certain

embodiments of the invention, the invention is not limited to the embodiments described above. Modifications and variations of the embodiments described above will occur to those skilled in the art within the scope of Claims..

[0075] The embodiments of this invention in which an exclusive property or privilege is claimed are defined as follows: